

Design, Construction and Evaluation of a Potable Dc-Dc Handset Charger

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ABSTRACT

Buck converter is a direct current-direct current (DC-DC) power tool that can be used for changing value of DC voltage to another value lower than the original input supply. DC-DC Converters are commonly used in electronic systems, for instance telecommunication systems, Personal Computers, and also used as charge controller for battery. The DC-DC converter is able to replace voltage regulator due to its higher efficiency. This type of converter is commonly used when the supply voltage from the source is higher for an electronic system, for instance charging battery by solar panel, buck converter is connected in-between the supply voltage from solar panel and the storage battery. Voltage from the solar panel is being drop to the value of battery charger. To stay connected to others, hand set charging has become part of our daily activities. A buck converter is designed and constructed to charge a handset in case of power failure from the grid. The DC source is either the lead acid battery, lithium-ion battery or directly from solar panel. The design and simulations were carryout using Proteus software. A reverse voltage protection was added to safeguard the charger circuit from being damage when connected wrongly. Materials were sourced from nearby electronics shops. The system was tested on different handset and found to be working properly.

Keywords: Bulk Converter, Direct Current (DC), Battery, Solar Panel

1.0 INTRODUCTION

A buck converter is a DC-to-DC power converter that lowers the voltage from the source to the load (in drawing a smaller average current). It is a type of switching power supply (SMPS) with at least two semiconductors (a diode and a transistor) and at least one energy storage element, such as capacitance, inductance, or a combination of the two (Alem & Blanca, n.d.)(Debolina Majumder, Muskan Mehta, 2019).

As DC-DC converters, switching converters (such as step-down converters) are more efficient than linear regulators (D'Amico, Mar'ia Bel'en; Oliva, Alejandro; Paolini, Eduardo; Guerin, 2006). Linear regulators are less complicated circuits that reduce voltage by dissipating energy as heat. However, the output current will not be increased. Buck converters are extremely efficient (often greater than 90%), making them ideal for converting the computer's primary (large-capacity) power supply voltage. Bidirectional DC-DC converters have currently gained slots in many applications such as hybrid vehicles, auxiliary power supplies, and battery charging–discharging for uninterruptible power systems (Wu & Lin, 2022)(Fan et al., 2022)(Wang et al., 2022). DC-DC converters can also be used for controlling the speed of electric vehicles (EV), and also for controlling other electronic devices in EV system (Suresh et al., 2022).

One of the most often used DC/DC converters is the step-down DC/DC converter, also known as Buck

converter. The buck converter may reduce a greater DC voltage to a lower DC value, such as from 24V to 12V or 5V. The buck converter offers a wide range of applications, low losses, and great efficiency (Masri et al., 2012)(El-zanaty et al., 2017)(Y.-E. Wu & Ke, 2021).

2.0 THEORY

2.1 Buck Converter

A buck converter is a step-down converter. For a DC–DC converter, input and output voltages are both DC (Falih & Andika, 2017.). It uses a power semiconductor device as a switch to turn on and off the DC supply to the load. The basic operation of the buck converter has the current in an inductor controlled by single switches with a diode or two switches. The switching action can be implemented by a BJT, a MOSFET, or an IGBT. Figure (1) shows a diagram of a buck converter that accepts a DC input and uses pulse-width modulation (PWM) of switching frequency to control the switch. An external diode, together with external inductor and output capacitor, produces the regulated dc output.

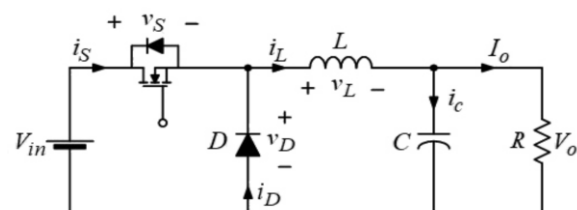


Figure: 1. Schematic of Buck Converter

2.2 Basic of Operation

In an idealized buck converter, all the components are considered to be perfect. Specifically, the switch and the diode have zero voltage drop when on and zero current flow when off. Also. The inductor has zero series resistance. Further, it is assumed that the input and output voltages do not change over the course of a cycle (this would imply the output capacitance as being infinite). The ratio of output voltage, V_o to input voltage, V_i can be adjusted by varying the duty ratio of switch using PWM Signal (Road, 2016.). In the PWM switching at a constant switching frequency, the switch control signal V_{tri} , which controls the state (on or off) of the switch, is generated by comparing a signal-level control voltage V_{ref} , with a repetitive waveform as shown in Figure 2 (Lopa et al., 2016)(Falih & Andika, 2017.).

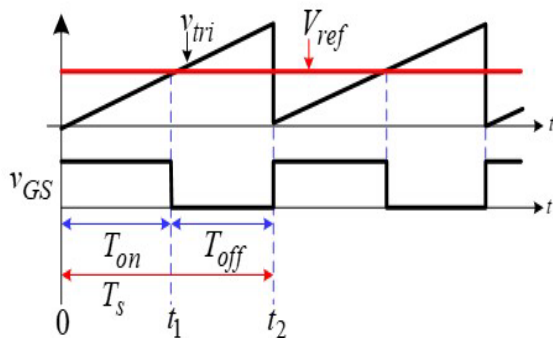


Figure: 2. Switch Control Signal Generation

The frequency of each cycle is called switching period T_s . If carrier signal voltage V_{trig} is above V_{ref} , switch will be changing state to off and vice versa. To control the duration of on T_{on} or $0 - DT_s$ is by changing the voltage reference V_{ref} . the ratio between V_{ref} and V_{trig} known as duty ratio of switch or called duty cycle. Duty cycle is always being presented in percentage value. A 60% duty cycle means the power is on 60% of the time and off 40% of the time. The switch duty ratio can be expressed as;

$$\frac{V_{ref}}{V_{trig}} = \frac{t_{on}}{t_s} = D \quad 1$$

(El-zanaty et al., 2017) Basic Switching, is have a very high ripple and not acceptable for any use, thus we need to add low pass filter such as inductor and capacitor to compensate the output ripple. The buck converter can operate in two different modes; continuous conduction mode (CCM) and discontinuous conduction mode (DCM). The difference between the two is that in CCM the current in the inductor does not fall to zero. A buck converter operates in continuous mode if the current through the inductor never falls to zero during the commutation cycle. In DCM, the current through the inductor falls to zero during part of the period. Practically, converter can operate in either operation

mode, but the design point or component selection will be based on the heavy load and this is mostly at CCM. So, in this design, we will be considering to use a CCM operation. The operation of a buck converter happens in two modes. The first mode is when switch close or on, and the second is when switch open or off.

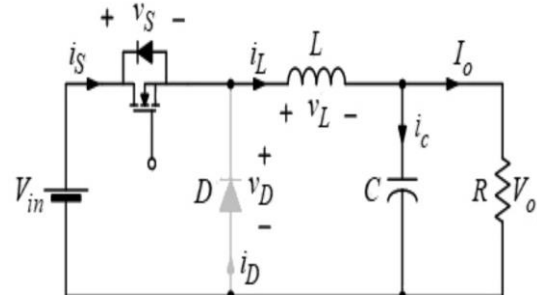


Fig. 3. Switch is on

When switch closes shown in Figure 3, voltage in the gate is high V_{GS} and current I_s flows from the supply voltage V_i through the switch. Inductor current I_L flow through inductor L and into the load, thus charging the inductor by increasing its magnetic field. Diode D will be on reverse bias, thus blocking the path for current. Thus, supply Voltage V_i will be same as diode Voltage V_d . Inductor current flows into load I_o and Capacitor i_c thus store energy and smoothing the output ripple. From Kirchoff Current Law.

$$V_S = 0, V_D = V_{in} \quad 2$$

$$-V_{in} + V_o + V_L = 0 \quad 3$$

$$V_L = V_{in} - V_o \quad 4$$

when current flow to an inductor, or charging, calculation can be with this equation

$$\frac{di_L}{dt} = \frac{V_L}{L} \quad 5$$

When the switch opens shown in Figure 4, the voltage on the switch gate V_{GS} is low, so power supply V_{in} is no longer connected. The inductor acts as a source and maintains the current through the load resistor thus make the diode become forward bias and current may flow.

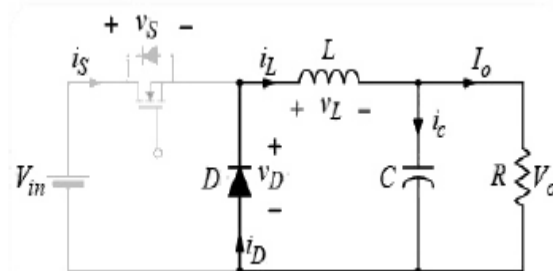


Figure: 4. Switch is off

During this period, the energy stored in the inductor decreases and its current V_L falls. Current continues to flow in the inductor through the diode D as the magnetic field collapses and the inductor discharges. The circuit equation can be made using Kirchoff Current Law.

$$VS = Vin, VD = 0 \tag{6}$$

$$VL = -Vo \tag{7}$$

When current flow to an inductor, or charging, calculation can be made with this equation.

$$\frac{di_L}{dt} = \frac{V_L}{L} \tag{8}$$

control circuit which contains the primary functions required for buck, boost and buck boost DC-DC converters. (Current et al., 2013) The devices also consist of an internal temperature compensated reference, comparator, controlled duty cycle oscillator with an active current limit circuit, driver and high current output switch. This IC was specifically designed to function with a minimum number of external components. In step-down operation the output switch current is of 1.5 A, the step down configuration of the IC as contained in the datasheet is shown in figure 5 (Current et al., 2013).

3.0 BUCK CONVERTER DESIGN
3.1 Switching Regulator Control Circuit

In this study the buck converter was designed using MCZ34063C, it is a monolithic switching regulator

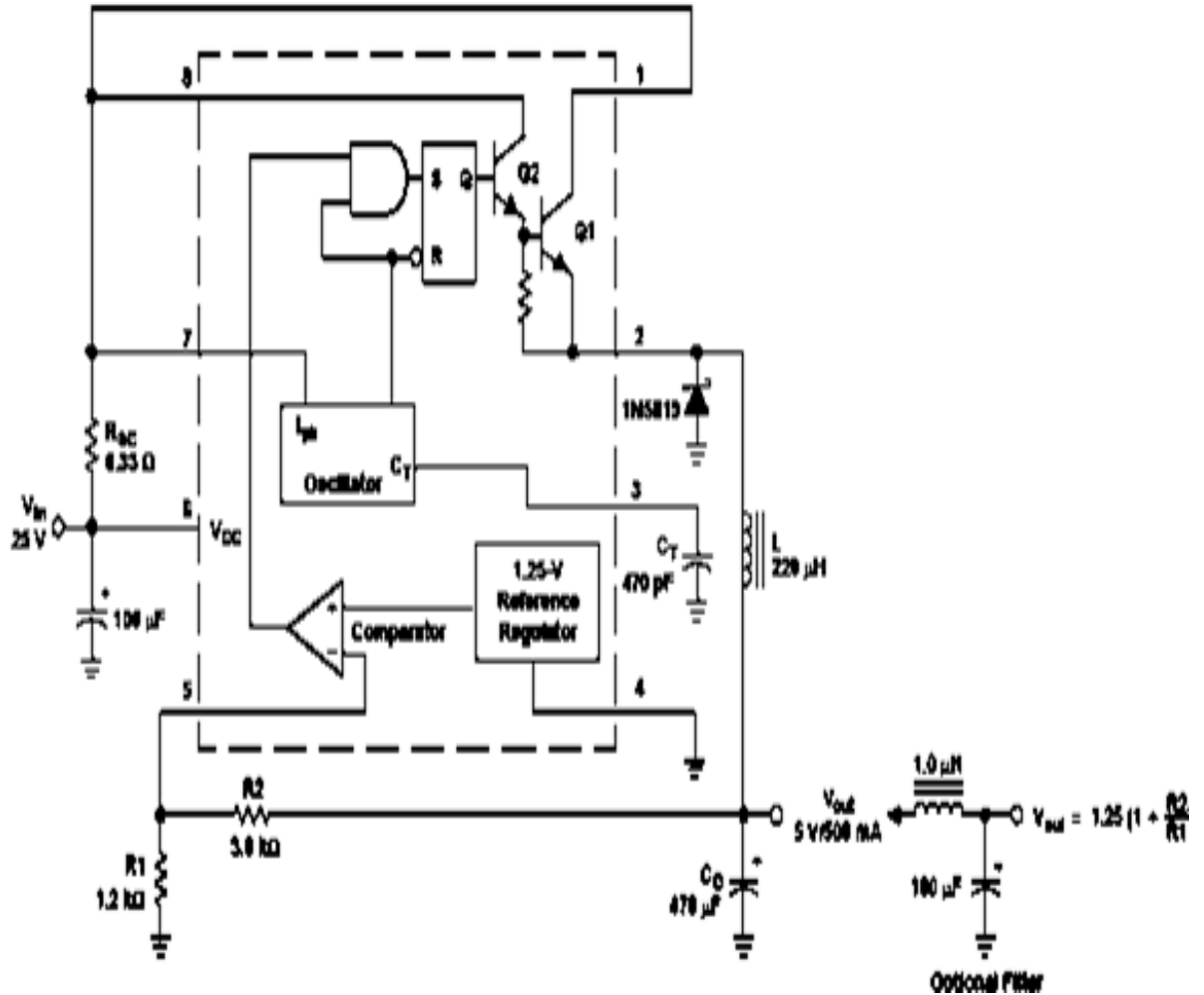


Figure:5 Step-Down Converter

For easy design calculations application information is | capacitor values were also given as 220µH and 100-220µF (Boost et al., 2005).

$$\frac{t_{on}}{t_{off}} = \frac{V_{out} + V_F}{V_{In(min)} - V_{sat} - V_{out}} \quad 9$$

$$(t_{on} + t_{off}) = \frac{1}{f} \quad 10$$

$$t_{off} = \frac{t_{on} + t_{off}}{\frac{t_{on}}{t_{off}} + 1} \quad 11$$

$$t_{on} = (t_{on} + t_{off}) - t_{off} \quad 12$$

$$C_T = 4 * 10^{-5} t_{on} \quad 13$$

$$I_{pk(switch)} = 2I_{out(max)} \quad 14$$

$$R_{SC} = \frac{0.3}{I_{pk(switch)}} \quad 15$$

$$L_{(min)} = \left(\frac{V_{in(min)} - V_{sat} - V_{out}}{I_{pk(switch)}} \right) t_{on(max)} \quad 16$$

$$C_O = \frac{I_{pk(switch)} (t_{on} + t_{off})}{8V_{ripple(pp)}} \quad 17$$

$$V_{out} = 1.25 \left(1 + \frac{R_2}{R_1} \right) \quad 18$$

V_{sat} = Saturation voltage of the output switch

V_F = Forward voltage drop of the chosen output rectifier

V_{out} = Desired output voltage

V_{in} = Nominal input voltage

I_{out} = Desired output current

F_{min} = Minimum desired output switching frequency at the selected values of V_{in} and I_{out}

V_{ripple} = Desired peak to peak output ripple voltage (Boost et al., 2005)

To charge a handset a potential difference of about 5 V is required. Applying equation 18, R_1 and R_2 were chosen to be 1 K Ω and 3 K Ω respectively. The design shows an output potential difference of 5.0 V. R is a current sense resistor, should be ranging from 0.22 to 0.33 Ω as contained in the datasheet.

3.2 Protection Devices

Most of electronic equipment that were designed to operates from a battery were fitted with an internal diode in series with one battery lead, to protect the equipment from damage if the connections to the battery are accidentally reversed (Electronics, 2000). (Aruna, K. and Rubasinghe, 2012) The most common procedure of reverse-voltage protection employs diodes for this purpose. For the first instance is a series diode that allows current to flow only if the correct polarity is applied. Second instance a bridge rectify can also use at the input so that the circuit always receives the correct polarity. Although the two approaches have a drawback due to voltage drop and power losses due to heat when power requirement is a bit high. The bridge rectifier approach was chosen for this study because the power requirement is low. This option also has an

added advantage in the sense that any of the two input terminals can acts as either positive or negative.

3.0 MATERIALS AND METHOD

3.1 System Design

The parameter of the buck converter module is shown in Table 1. Moreover, the switching frequency, voltage ripple and maximum current were contained in the IC's datasheet.

Table: 1 Design Parameters of the Proposed Converter

S/N	Variable	Symbol	Value
1	Input Voltage	V_i	7-24 Volt
2	Output Voltage	V_o	5.0 Volt
3	Output Power	P_o	7.5 Watt
4	Switching Frequency	F_s	100 kHz
5	Output Voltage Ripple	$\Delta V_o\%$	2 %
6	Inductor Current Ripple	$\Delta I_L\%$	10%
7	Output Current	I_{max}	1.5 A

3.2 Reverse Voltage Protection Circuit Design

A bridge rectify diode arrangement was connected at the input of the charger circuit, so that the circuit always receives the correct polarity. (Aruna, K. and Rubasinghe, 2012) The drawback of these approaches is that they waste power in the voltage drop across the diodes. For this work the power requirement is low, hence have negligible impact on the system.

The materials used in system construction were listed in table 2.0. The circuit diagram was being prepared with "Proteus Intelligent Schematic Input system (ISIS)", is presented in Figures 6

Table 2.0 Material Used for System Construction

S/No	Component	Description	Quantity
1	Integrated Circuit (IC)	MU34063C	1
2	Resistor	0.22 Ω	1
3	Resistor	3 k Ω	1
4	Resistor	1 k Ω	1
5	Resistor	2.2 k Ω	1
6	Capacitor	100 μ F	1
7	Capacitor	220 μ F	1
8	Diode	FR102	1
9	Diode	1N4002	4
10	LED	Red	1
11	Inductor	220 μ H	1
12	Capacitor	1 nF	1

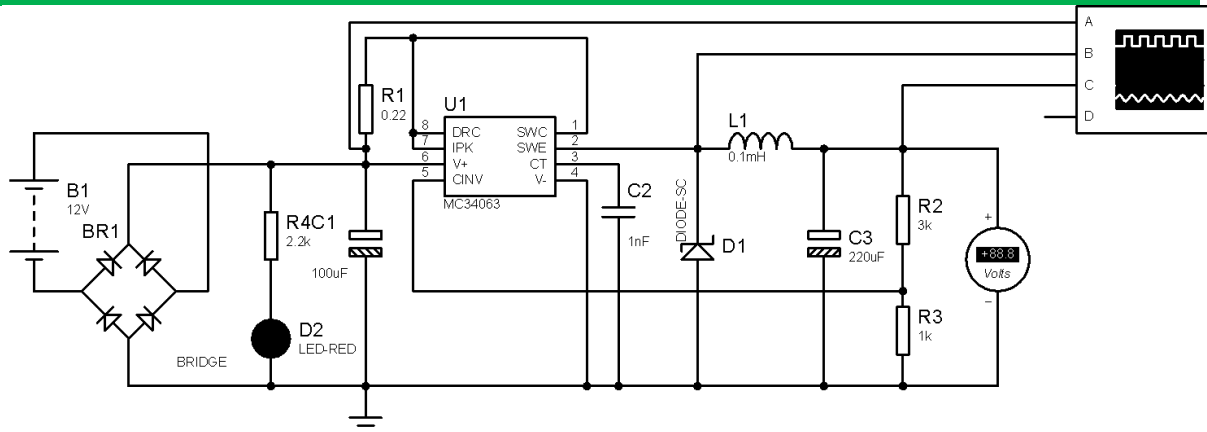


Figure: 6 Complete Circuit Design

3.4 System Construction

All the components were tested before soldering and IC socket was used for safety. Both the two sections of the design were on the same Vero board. A 100 µF smoothing capacitor across added across the circuit to improve transient response and stability of system. The photograph of the charger is shown in plate 1.0.

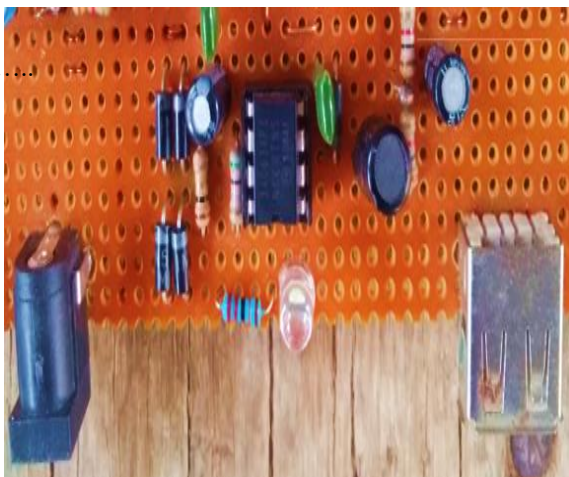


Plate: 1.0 Photograph of the constructed circuit

4.0 RESULTS AND DISCUSSION

Simulations of the circuit were captured as shown in figure 7, 8 and 9.

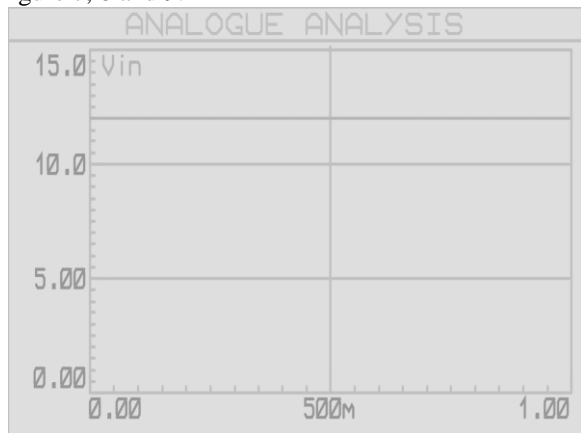


Figure: 7 Simulation of the input supply (starting from 0 – 1 sec) in Proteus

The result shown in Figure 7 is the input voltage of 12 Volt

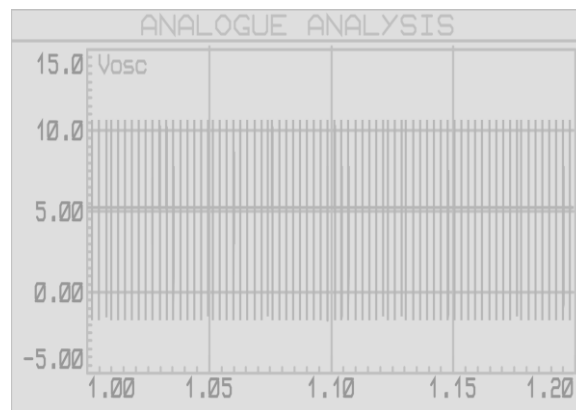


Figure: 8 Simulation of the PWM IC (starting from 1 – 1.2 sec) in Proteus

The result from the oscillator (Figure 8) shows a square wave output of frequency 100 kHz, and it tally with the manufacture’s report.

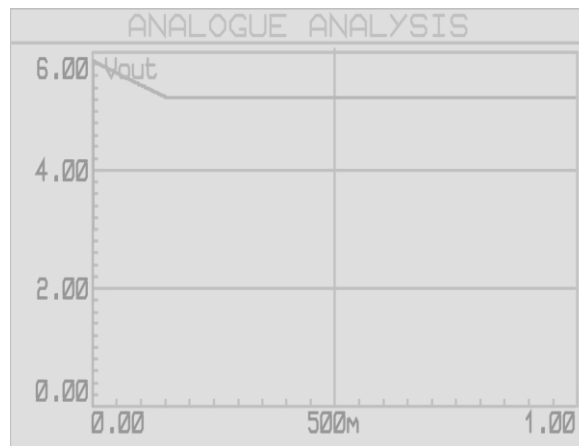


Figure: 9 Simulation of the Charger Output (starting from 0 – 1 sec) in Proteus

The outcome of the result shows a voltage spike of about 9% for a period of around 125 milliseconds.

Then latter settles at 5.0 volt in an open loop. Red LED is an indicator showing the circuit is connected to the input supply.

4.1 System Tests

After the construction exercise, the circuit was tested to ascertain its working condition. The test was carried out in two stages. (i) A digital voltmeter was connected across output of the circuit while the input supply is being altered. Same procedure was followed but simulating the circuit with Proteus. The observations obtained for the two situations were recorded and represented graphically as shown in Figure 10. (ii) The charger output was connected in series with a digital multimeter before connected to the handset battery (Li ion). The charger was then connected to solar panel of 30 watts. The charging current was noted for an interval of 15 minutes and represented graphically as shown in Figure 11. Figure 10 shows that the simulation result is more accurate than the actual constructed circuit, this could be due to the tolerance of the components used. Figure 11 shows that at initial stage of the charging high current is being used and latter it continues to diminishes gradually till it reaches zero. At this stage the battery is said to be fully charge.

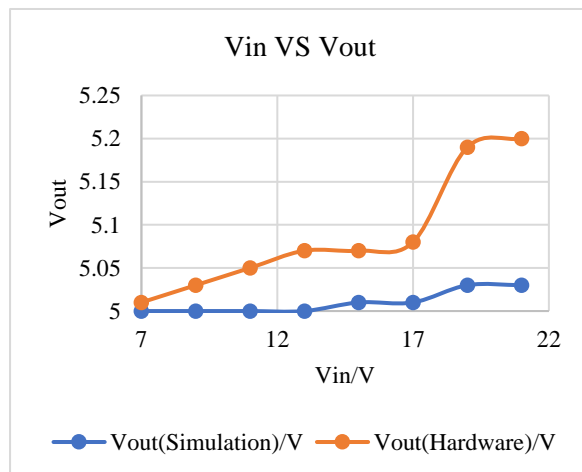


Figure: 10 Comparison Between Experimental and Simulated Output

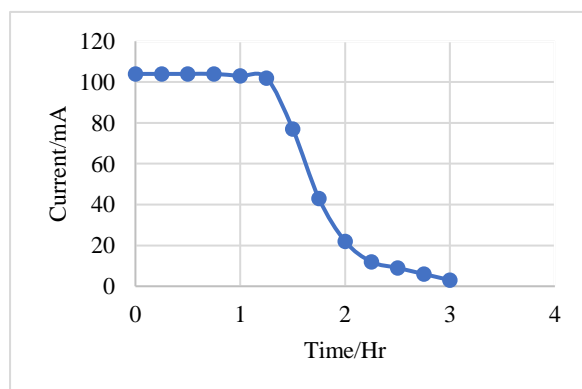


Figure: 11 Plot of Charging Current Against Time (200 mA Battery)

5.0 CONCLUSION

The system can appropriately step down 7-24-volt DC input to 5-volt DC. The test conducted shows that it is suitable for charging handset. In absence of AC from national grid the charger is found to be useful. Reverse protection attached to the system will also improves the life span of the charger.

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